Chapter 5
Mankind's Artificial Eco-system

Growth for the sake of growth is the ideology of the cancer cell
Edward Abbey

"The general public, businessmen, governments, and many business economists appear to believe that population and per capita consumption can grow indefinitely, and that eventually all economic inequities can be eliminated by growth itself. To me and my colleagues, this is an entirely unwarranted assumption—and debunking it may be the single most important task of environmental and resource economists
Paul R. Ehrlich

5.1 Thermodynamic Symptoms

The power of thermodynamics to provide insights into the nature of complex systems has been fully investigated in previous chapters and that exploration has furnished us, hopefully, with a platform to examine global warming and climate change. At the time of writing, in 2010, it is becoming rather difficult to refute the evidence for such change, when many indications, of an environmental nature, are increasingly being identified and reported. Nevertheless the topic is still considered to be controversial, certainly by the media, which seems to delight in maintaining and prolonging the misinformation storm, stirred up by well resourced nay-sayers and deniers. So to help consolidate conventional explanations of the nature of the observed climate anomaly we shall seek assistance from the laws of thermodynamics, which as we have seen, govern those equilibrium and non-equilibrium systems that in crude terms degrade energy.

It may be useful at this juncture to very briefly recapitulate relevant aspects of the preceding chapters, in order to reinforce the message that the laws of thermodynamics represent rather powerful analysis tools. Firstly, it was observed in Chap. 1 that in a closed adiabatic system—an example would be a steam engine together with its energy source, housed within an insulated and isolated chamber—the overall quality of the energy in the fuel will over time be degraded inexorably, as the engine delivers mechanical power. Entropy rises steadily in the form of residue, greenhouse gases and low grade heat. Or more generally, we can say that in a closed thermodynamic system, heat always flows spontaneously from a hotter reservoir to a colder one, perhaps doing work on the way, until there is no longer a temperature difference or gradient. The thermodynamic engine can be said to operate by gradient reduction.

Actually, this gradient reduction property is not exclusive to man-made machines but it also exists in nature, as we have seen in Chap. 2. There, we showed that equilibrium thermodynamics can be employed successfully to

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rationalise and explain the energy flows associated with processes which are essential to life, such as photosynthesis and animal metabolism. The evidence is that these flows accord fully with the laws of thermodynamics, for systems operating close to equilibrium. However, in the context of equilibrium thermodynamics living organisms present a difficulty for thermodynamics in that, as closed systems, they appear to contravene the second law. Entropy is seen to decrease (negentropy) in the process of building biomass. This problem is resolved by treating living systems as 'open' in a non-equilibrium thermodynamic paradigm. In Chap. 3 it is established that by accessing low entropy radiant energy from the Sun plants temporarily defy the second law in creating low entropy biomass by photosynthesis. This biomass is then a source of food for further low entropy cellular build-up in animals, as well as being a source of muscular energy. The penalty is waste production, resulting in high entropy low grade energy percolating into the environment. The biosphere, on the other hand, when viewed as a complete thermodynamic system, does not flout the second law. But the laws of thermodynamics in a non-equilibrium context dictate that ecosystems, and the biosphere as a whole, accommodate biodiversity in a symbiotic, mutually reinforcing gradient degrading system, which benefits not just the individual plants and animals within it, but the surrounding environment, keeping the ecosystem, and even Lovelock's 'great Earth system' as he terms it, in thermal equilibrium.

To the satisfaction of most scientists and interested observers, with an affinity for rational solutions based on evidence, climate science has unequivocally demonstrated that current global warming patterns are not related to solar cycles or sun spots [1]. In fact, if they were, then on the basis of historical trends the Earth should be entering an ice age [2]. Core activity within the Earth's magma itself, since volcanic activity has been relatively benign for a very long time, can also be ruled out. As an applied scientist with a long interest in thermodynamics, it is therefore difficult not ask—if the heat build up on Earth is not associated with changes in the Sun's output, or Earth's core, what is causing it? The first law of thermodynamics has to be satisfied, and the only rational answer is that the source must be 'ancient sunlight' released by the burning of fossil fuels. While the direct heat released into the atmosphere from homes, power stations, factories and vehicles is insignificant in global thermodynamic terms, the influence on the biosphere of added carbon from ancient forests is not.

The warming mechanism can be illustrated, in simple terms, by the application of relatively elementary thermodynamics to a typical garden greenhouse (see Chap. 12). Straightforward calculations show rather clearly that the introduction of a heat insulating argon layer between the panes of glass (double glazing) has a very significant effect on the equilibrium temperature maintained by the greenhouse. Furthermore it illustrates that an argon layer, which in volume is just over 0.15%, or 1500 ppmv, of the volume of the greenhouse itself, produces a very substantial temperature increase of nearly 50%. The evidence from thermodynamics is that thermal systems such as the biosphere are likely to

be sensitive to the introduction of insulating mechanisms in the guise of greenhouse gases. Of course, the biosphere is immensely more complicated than a greenhouse. Nevertheless the analogy indicates that by burning fossil fuels and returning carbon to the atmosphere in the form of carbon dioxide molecules, which act like thermal insulation, humans are introducing an additional warming mechanism into the biosphere. It would clearly have been better for the biosphere if much of this fossil fuel bounty had been left where it belonged, safely sequestered deep within the planet as it has been for millions of years. In medical terms we are functioning much like a 'virus' infecting the body of an animal (the Earth system) which, if we prolong the medical analogy, is naturally suffering from 'a temperature'.

So how did mankind attain the ability to interfere in such a major way with the global climate, and the 'great Earth system'? Most of us would probably be inclined to judge that the planet is far too vast to be susceptible to insignificant humans on its surface, but is it?

5.2 Drifting Towards Ecocide

If you have ever viewed night time satellite images of the Earth (they are available on the internet), when the surface is not shrouded in cloud, the evidence of the presence of mankind is staggering. Excess light now splashes over virtually all of the industrialised nations of the globe. Cities, towns, villages, motorways, trunk roads and other travel routes are easily identified. Because of the range of technology, which is now available to mankind, the footprint of each human being on the surface of planet Earth is by no means insignificant. It is quite clear, that the relentless advance of technology, since the industrial revolution, could not have occurred at the rate that it has, without copiously available, inexpensive fossil fuels. But, as we have seen, concern about the waste products generated by widespread fossil fuel incineration was being expressed very early in the steam age, in fact as far back as 1850. In particular, scientists at the time, such as Fourier and Arrhenius, were greatly exercised by the unprecedented levels of exhaust gases, and other products, which were being dumped into the atmosphere. So cautionary papers were emanating from the science community from a very early stage in the industrial revolution, but they did not become really coherent for several more decades. As Mooney and Kirshenbaum have noted, in their recently published book 'Unscientific America' [3]:

> Scientific warnings about global warming go back decades, yet our political system has repeatedly failed to take action. We now find ourselves in a harsh predicament: Even if we move quickly to address the problem, some effects of global warming could still be devastating and irreversible.

For over 150 years, economic and technological growth has proceeded as if 'there were no tomorrow', with no discernable concern for the environment, other

than in some small pockets of the scientific community and among scattered groups of agitated 'greens'. While some of the reasons, why this should be, have already been addressed elsewhere [3], it is perhaps pertinent to review the process by which human civilisation has reached its current highly technological composition, to give us a platform from which to consider the problem of reversing the growth of greenhouse gases.

Arguably five primary science/engineering developments have underpinned the advance of modern civilisation: these are the steam engine, the electric/motor/generator, the internal combustion engine, the jet engine and the transistor. The contributions of these pioneering activities to the global heating saga will be summarised below.

5.2.1 Growth Based on Steam

Following the sterling efforts of Newcomen, Watt and Carnot in establishing viability of the steam engine, it was soon being introduced to a range of applications beyond that of the industrial 'work horse', where it started. In both the UK and the USA it was not long before it was adopted to propel ships from ocean going liners to tugs, and of course the steam engine was the key to the creation of railways. In the UK the railway boom [4] began in the 1930s following both the success of the Stockton to Darlington railway, and the significant improvements in engine capability brought about with Robert Stephenson (1803–1859). His Rocket arguably marks one of the key advances in railway technology. It also confirmed Stephenson as one of the premier engineers of his age and as a major engineering contractor for the emerging railway network, both in Britain and abroad. The locomotive was built to compete in the Rainhill Trials in 1829, held by the new Liverpool and Manchester Railway, with the aim of choosing between competing designs. The Rocket, which proved to be substantially superior to its rivals, had as it turned out, established the design template for all subsequent steam locomotives. The basic design principles embodied in the Rocket were to persist right through to the building in Britain, during the 1960s, of the last steam locomotives. Soon railway systems were spreading out into the continent of Europe, into America and beyond, hugely increasing the demand for coal, which by the beginning of the twentieth century was also being used in factories, in steel making, in shipping, in heating, to form coal gas and to generate electrical power. The growth rate in coal use (see Fig. 5.1 and note the logarithmic scale) at this time became positively immense. By the turn of the century, atmospheric carbon dioxide had grown from its long term concentration level of 280–300 ppmv, a not insignificant 7% rise. Humans were beginning to 'make themselves felt' in ecological terms, and it had been noted by the science community. By this time Arrhenius had published evidence of the possible sensitivity of the climate to small changes in atmospheric CO_2.

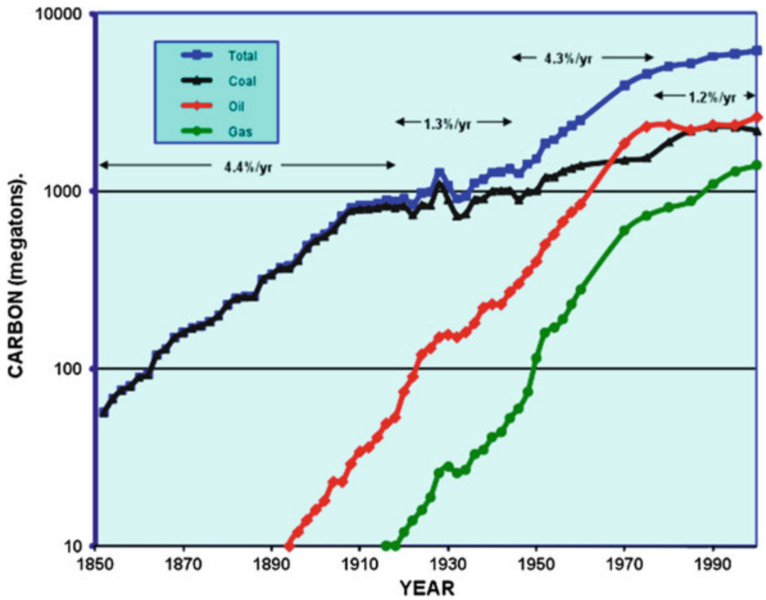

Fig. 5.1 Growth of atmospheric carbon since 1850 (from Hansen [7])

As we discovered in Chap. 1, no heat engine can be more efficient than dictated by the theoretical limit of the Carnot cycle. For the greatest efficiency, steam engines should be operated at the highest steam temperature possible (superheated steam), and release the waste heat at the lowest temperature possible. In practice, a steam engine exhausting the steam to the atmosphere will typically have an efficiency (including the boiler) in the range of 1–10%. At these efficiency levels, 90–99% of the coal is being burnt purely to heat and pollute the environment! It takes considerable ingenuity to improve on this figure but with the addition of a condenser and a multiple expansion system, which is easier in very large engines, efficiency may be greatly improved to 25% or better. An electrical generating station delivering megawatt levels of power, for example, with steam reheat, economizer etc. can achieve up to 50% thermal efficiency. Even so half of the combusted coal is doing no more than generate waste heat and unwanted gaseous products. So, with no way of circumventing this inherent inefficiency of steam engines, particularly in the limited size engines required by transport (railway steam engines were typically 3% efficient [4]) alternatives were sought. For engineers, in the absence of economic imperatives, the motivation, which drives technological progress, is the search for more power, more speed, more efficiency, more reliability, and more control. So it is not surprising that technologists were soon looking elsewhere, for more efficient substitutes to the steam engine, not from concern for the environment, but to improve responsiveness and reduce running costs.

5.2.2 Electric Power

One answer was furnished by electrical science. The early history of electrical engineering is well documented in many textbooks [5], and abundant information on past developments can be found on the internet. In relation to electrical power generation, suffice to say that following early pioneering work, by an extensive list of contributors, Michael Faraday (1791–1867) was the first to demonstrate a practical electric motor, and he did this in 1821. There followed a flurry electrical innovation and development over the next 40–50 years culminating in a direct current (DC) electric power generation system to supply mercury arc lighting in San Francisco. This appeared in about 1880. At about the same time more versatile alternating current (AC) electrical supply systems were being built in Europe, such as the 100 mile long, 30 kV AC transmission line which was erected in Germany in 1891. These early generators were either powered by water turbines in hydro-systems, or more commonly, by coal fired steam turbines.

The growing availability of electricity spawned a whole new category of consumers of power. These included suppliers of lighting and heating systems, users of compact and versatile machine tools, and operators of electrical telegraphy and telephony, all this made possible by copiously burning coal, consumption of which continued to rise exponentially. In the transport sector, and in America, the first electrification of a steam railroad occurred in 1895, but it is doubtful if these early electric trains were any more efficient in their use of coal than the steam locomotives which they replaced. Coal power stations at the time were little more than 20–25% efficient, while steam turbines, electrical generators, transformers, electricity transmission lines, and the locomotives themselves all exhibit resistive heating losses. Consequently at the point of traction, between the locomotive's wheels and the rails, the efficiency of the use of the energy in the original coal was likely to have been little more than 5%. So 95% of the incinerated coal was uselessly polluting and warming the local environment. In essence this was little different, in environmental terms, from burning all of the originally mined coal on open fires! But coal was so inexpensive, that this gross level of inefficiency was not considered to be a hindrance to continued development. Furthermore, the higher than necessary levels of atmospheric pollution, which accrued from lax engineering practices, were of no consequence to most people during the early part of the ninteenth century. As we shall see, from an economic perspective, plundering coal from the ground, and polluting the atmosphere with the waste products resulting from combustion, was largely an 'off balance sheet' externality.

5.2.3 The Oil Bonanza

The inherent inefficiency of steam engines caused by the fact that the burning fuel only indirectly powers the mechanical parts—via steam—hastened the

development of internal combustion engines, initially powered by coal gas. An early version appeared in France in 1860. However, these gas fuelled engines were short lived, since they still represented an inefficient use of the original coal. The picture changed completely with the establishment of the first petroleum well, in the summer of 1859, in the Oil Creek region of northern Pennsylvania. This well produced oil at the rate of eight to ten barrels a day, but this was soon to increase hugely with the sinking of wells in Texas.

The first working oil powered internal combustion engine is attributed to George B. Brayton (1830–1892), a US mechanical engineer, who patented his two cycle continuous combustion engine in 1874. However the really significant breakthrough came with the German engineer, Karl F. Benz (1844–1929). In 1885 he revealed the first reliable internal-combustion engine—later incorporated into a three wheeled vehicle, which history records as being the first recognisable car. It actually looked more like a powered tricycle than a car [5], but it was the start of a transport revolution, which resulted in a major switch from coal to oil. The evidence can be seen in Fig. 5.1, where the rapid rise in oil consumption from just before 1900 coincides with a slowing in coal consumption.

Thermodynamically, power is generated in an internal combustion (i.c.) engine by the exothermic (heat expending) chemical process of combustion, when fuel (mostly petrol) is mixed with air and ignited (usually, but not necessarily, by an electrical spark). The explosive chemical reaction develops a great deal of heat, as the hydrocarbons in the fuel react with oxygen in the air to produce steam and carbon dioxide and small proportions of other chemicals at high temperature. Chemical energy in the fuel is converted to thermal energy. The power in the rapidly forming heat, of course, drives the mechanical parts of the engine to yield useful output. The ratio of mechanical output to latent explosive power in the fuel is generally adopted as a measure of the thermal efficiency of an internal combustion engine. Since combustion chambers are formed predominantly from metals, which can withstand only so much temperature rise in the contained hot gases, the Carnot thermodynamic limit is dictated by the permissible ignition temperature. For an engine with steel lined cylinders for example the optimum efficiency is 37%, but is more likely to average at around 18–20% in mass produced automobile engines. A profligate 80% of the heat of the combustion merely warms the engine block and its surroundings, and together with waste gases, it also disappears down the exhaust pipe. Nevertheless, by comparison with steam locomotives and electric vehicles powered from coal fired power-stations, the improvement in thermal efficiency is still very substantial. Significantly, compact power units based on internal combustion were found to be much easier to realise. Needless to say the rapid evolution of our oil based economy, from 1900 onwards, was inevitable.

Notwithstanding the attractions of electric power, electrification of the railways was undoubtedly sluggish. This was mainly due to the emergence of diesel electric locomotives. These prime movers brought to the railways the efficiency improvements inherent in the internal combustion engine. However because of the very high levels of power (typically 2 MW) which they were capable of

delivering, to haul heavy freight and passenger trains, speed control through gear trains or hydraulic transmission systems, as used in automobiles, was not possible. A gear train would soon be stripped of teeth in transmitting the huge torques involved. The solution was the diesel electric system in which the diesel engine drives an electrical generator. The generator is then coupled electrically to a highly controllable electric motor which drives the wheels. In engineering terms the marginal loss of efficiency is a very acceptable trade-off for the gain in control. Of course diesel engines were used much more widely than in the railways. In addition to industrial applications they became the 'workhorse' of the road haulage industry, contributing substantially to the demand for oil as Fig. 5.1 attests, and as a result of the poor thermal efficiency of heat engines much of it just percolates into the atmosphere. When one reviews the engineering history, it is a rather curious fact, that the poor efficiency and wastefulness of fossil fuel based prime movers has generated remarkably little interest or attention throughout most of the twentieth century.

5.2.4 Mass Air Travel

Aircraft represent a strictly twentieth century phenomena: a success story for science and technology. The solution to the problem of demonstrating powered flight lay in bringing together early developments in engines with aerodynamic advances on primitive gliders. In 1876 a suitable four stroke internal combustion engine had been demonstrated by Nikolaus Otto (1832–1891), while a few years later Otto Lilienthal (1848–1896) had made considerable inroads into the science of gliding. These developments together with ideas from other groups investigating motive power and aeronautics were synthesised in the first propeller driven powered aircraft built in 1903 by the American brothers Wilbur (1867–1912) and Orville Wright (1871–1948). Over the ensuing twenty five or so years flying machines evolved rapidly from bi-planes to monoplanes, and from simple two-cylinder four stroke engines to multi-cylinder radial engines. But it was soon realised that the propeller/piston engine combination was very limiting. Engineers were by 1940 seeking to circumvent the speed and altitude restrictions imposed by this mode of propulsion.

The turbo-jet, which revolutionised air travel, can be considered to be an evolutionary development from the Brayton two cycle, continuous combustion engine. It has a thermal-air-jet format consisting of a compressor, a combustion chamber and a turbine. The compressor at the front of the engine, behind the air intake, is shaft driven by the turbine at the rear, and is designed to build up the pressure in the incoming air. The pressurised air then enters the combustion chambers where the oxygen in the air burns continuously with the injected fuel. Thermodynamically, this is more efficient than pulsed power delivery, as employed in the closed chambers of a reciprocating internal combustion engine. The explosively expanding hot gases, in the expansion chambers of the jet engine,

power the turbine, while the spent products and unused hot air escape through the exhaust nozzle at the rear of the engine at very high velocity. The reaction force generated by the high speed ejection of gas propels the aircraft forward. This high speed, high altitude capability for aircraft, which the jet engine provides, comes at a penalty. It is less fuel efficient that an internal combustion engine of similar power. So its pollution potential in high flying aircraft is substantial, with more than 80% of the fuel carried by the aircraft simply being spewed into the stratosphere as spent gases. There, it does more harm than at ground level. The consequence is that the delivery of air travel to all parts of the globe, for very large numbers of people, has become an activity, which while popular, is immensely harmful to the biosphere. The ecological implications of lifting very large numbers of people into the stratosphere, by burning fossil fuel energy in relatively inefficient jet engines are clear. It would undoubtedly be much less polluting to move them around more slowly at surface level. However, this hardly accords with modern 'high powered' lifestyles.

5.2.5 Computer Revolution

Modern manifestations of high speed communication, from radio to television to the internet, are all dependent on electronics. Electronic systems are now extremely complex in their functions and capabilities, largely in response to innovative design and development methods and clever use of sophisticated fabrication techniques relying on advances in material science. But at the outset this was not so, when Heinrich Hertz (1857–1894) began to experiment in 1886 on radio waves emitted by spark discharge tubes. As it turned out, his measurements of the nature of radio waves were to provide confirmation of the theories of James Clerk Maxwell, which had been published some 20 years earlier. While Hertz was sceptical of the communications possibilities of radio waves, nevertheless Oliver Lodge (1851–1940) persisted with the idea and demonstrated a primitive transmitter, which he termed a 'coherer', and a receiver ('de-coherer') in 1894. By this time, of course, due to the endeavours of the Scottish born Alexander Graham Bell (1847–1922) and many others, telegraph systems were already well established. Telephony was first demonstrated by Bell in 1876, and by 1877 there were 1300 commercial telephones in the USA [5].

At the same time that Lodge revealed his coherer, Guglielmo Marconi (1874–1937), by extending and improving the findings of Lodge and others, demonstrated the ability to transmit and receive radio waves over a distance of 1km. From this point on, radio communications and electronics 'took off'. The fortuitously concurrent discovery of thermionic emission associated with Thomas Edison (1847–1931) and the later invention of the vacuum diode by John Ambrose Fleming (1849–1945) and the triode by Lee de Forest (1873–1961) soon permitted quite sophisticated processing and control of

signals by means of electronic circuits. However, the era of the vacuum tube was short lived, with the invention of the transistor, which is generally attributed to William Shockley (1910–1989), 'the father of the transistor', around 1947. Apart from applications which entail operation at high power levels, semi-conducting devices have now largely superseded the vacuum tube in control and processing circuits, and they have opened up the whole area of logic circuitry. This development has culminated in the evolution of computers and processors, and these in turn have spawned the internet. As a result, since the 1950s the growth, of electrical and electronic devices, components, circuits and systems, has been staggering, as a cursory perusal of the statistical records soon confirms.

Thermodynamically, the relevance of this perusal of the unrestrained expansion of consumer electronics is that all electrical systems no matter how small, or large, require some power simply to push electrons through wires, in order to overcome resistance in conductors and circuits. This means electrical power loss and hence inefficiency is unavoidable and the losses must be supplied either from batteries or from the electricity grid. Either way, to supply this loss mechanism, fossil fuels have to be combusted to put energy into the batteries or to meet direct demands on the grid. Unfortunately, electrical goods, whether in the micro or macro category, are not as efficient as they could be—they generate not a little heat—as anyone who has handle a battery charger for a mobile phone will know. Every time a computer buff, or mobile phone user, switches on his/her machine the power station has to supply electrical power either directly or indirectly. If the electrical utility is coal based, the combusted coal drives an inefficient steam turbine which turns a generator with ohmic losses, which energises a transformer with ohmic losses, which stimulates power lines with ohmic losses, which feeds electricity to the end user through a step down transformer with more ohmic losses. So it is estimated that, for the whole chain, no more than 20% of the power extracted from the coal reaches the end user. The rest is used to pollute the environment. For every watt that the computer buff requires, to do useful computational work, when he powers-up his system, 4 W is wasted in simply generating heat. Furthermore for every watt which his machine draws from the mains, it dissipates about 0.1 W in its internal electronics. Consequently, with computer electronics in particular, but also many other electrical applications, growing globally at an exponential rate, more and more fossil fuel energised prime movers are needed to meet the rising demand. This is evident from Fig. 5.1 which shows total fossil fuel usage since 1950 increasing once more at almost 4.4%/year as it did between 1850 and 1900.

Most of the 'ancient sunlight' stored deep in the earth's crust where it has been safely sequestered for millions of years is being returned to the surface by mankind merely to pollute the atmosphere: very little of it (<5% at a guess) has been used constructively and intelligently to create significant artefacts or edifices, which are, or have been, of identifiable or lasting benefit to our species and our civilisation. The second law has reaped and continues to reap its inevitable harvest.

5.3 The Evidence of Ecocide

When it is related in the highly summarised manner perpetrated above, the story of the technical innovation, which has propelled civilisation since the beginning of the ninteenth century, appears to be one of untrammelled engineering success. But the huge expansion in the demand for fossil fuels, which it has triggered, now presents a dilemma for our species. Thermodynamics, in accordance with Carnot, dictates, as we have seen, that manmade prime-movers are limited in their efficiency, and therefore much of the heat and the waste products, of combusting fossil fuels, end up in the atmosphere. It took almost half a century before this problem was recognised. In fact until, as we have already noted, Guy Callendar a steam engine designer, was sufficiently concerned at the levels of CO_2 being exhausted into the air, that in 1938 he submitted a paper to the Royal Meteorological Society in London suggesting that planetary warming was a possible consequence of burgeoning CO_2 build up in the biosphere. It is unlikely that he was the only cautionary voice, because by this time, and certainly by 1950, smog and acid rain were beginning to afflict major cities in Europe and the USA in a very serious way.

5.3.1 Urban Smog

The dangers of air pollution were recognised by some perceptive humans at least 350 years ago, although admittedly it was experienced only at a very local level. A certain John Evelyn [6] highlighted the problem in a pamphlet with the quaint and old fashioned title “Fumifugium, Or the Inconvenience of the Aer, and the Smoake of London Dissipated”. Wood and coal burning fires apparently produced such dense effusions, when the weather was conducive, that they could be detected miles away. He suggested that London reeked like the ‘suburbs of Hell’. Nevertheless the problem was not a trivial one, since it harboured a distinct health risk. Statistical studies, in the seventeenth and eighteenth centuries, indicated that town dwellers were considerably more likely than country folk, to suffer and die from respiratory problems and lung diseases. Despite the quite striking evidence that coal burning, in the heating of homes and buildings, and later in the powering of the steam revolution, was a serious threat to health, it was to take another hundred years, incredible as that now seems to be, until burgeoning industrial society acknowledged that action was necessary.

The trigger was the great London smog. In early December 1952, contemporary reports describe a great mass of cold air expanding northwards from the English Channel and draping itself over London like a chilly blanket. It then simply stayed put. In trying to keep warm, Londoners chose to stoke their home and office fires more vigorously than usual, thus sending plumes of black, sooty smoke into the air, there mixing with clouds of exhaust gases billowing from the chimneys of

factories and coal-burning power plants. But instead of rising into the atmosphere and dispersing, the gas and smoke laden air stayed close to the ground, trapped by the still cold air blanket hovering above it. Over the next five days, a city already notorious for its smog experienced the worst air pollution it had ever seen. A thick sooty haze hung over the streets, seeping into homes and offices. News reports suggest that public transport virtually ground to a halt, and at night the visibility was so poor that it became impossible to navigate through some parts of the city. And as testament to how bad it really was, it is recorded that indoor concerts had to be cancelled because the audiences once in their seats, presumably those that lived locally and managed to find their way to the venues, could not see the stage!

But when the smog eventually lifted its after-effects were even more serious than dislocation. When the registrar general published the mortality figures three weeks later it was soon realised that there had, in fact, been a major disaster. Some 4,000 people died of respiratory ailments in those five days, and it is now clear that a further 8,000 probably succumbed in the months that followed. Not surprisingly, most of the victims were individuals who were especially vulnerable by reason of age or illness. Recent studies based on lung tissue samples preserved from the victims of what became known as the Great Smog of 1952, have provided insights into why the smog proved so deadly, and in particular the role of particulates.

For all sane and responsible citizens, clearly a Rubicon had been reached. The Great Smog is considered to be a turning point in environmental history. Although there had been other episodes where air pollution was held responsible for a spike in deaths—notably in the Meuse Valley in Belgium in 1930, and in Donora, Pennsylvania in 1948—the numbers were much lower than those in London. In the aftermath, British officials passed laws banning the emission of black smoke and requiring industry to switch to cleaner-burning fuels. The switch was largely to natural gas, and the contrasting global trends in gas and coal usage, after 1950, are manifest in Fig. 5.1.

5.3.2 Acid Rain

It should be noted that smog is not the only evidence of harmful poisoning of the environment triggered by the burning coal and other fossil fuels. When coal is combusted, it creates residues from the breaking down of organic compounds, and these waste products are made up of binary nitrogen and oxygen, among others. These then mix with water vapour in the air which through natural processes eventually forms raindrops. The water vapour is penetrated by the sun's rays, and if this occurs for a long enough time, it creates compound acids in the water droplets, also known as acid rain. Acid rain has been demonstrated to inflict long-term damage to trees and flowers. It also has a negative effect on plants, such as vegetables, fruits and other consumables. Acid rain can permeate rivers, streams and Earth's water supply as well, putting harmful components into our water supply systems. When it is inhaled, acidic water vapour is not conducive to good

health. It begets many of the same ill effects which are ascribed to the exposure to smog.

It is pertinent to note that respiratory problems not only debilitate people, but are present in animal life, too. This evident contagion of nature which has, and continues to be, accrued from burning ‘ancient sunlight’, will persist until alternate renewable sources of energy are adopted. However, the leviathan which is the ‘global carbon economy’ evinces huge inertia, and shows no sign of slowing down even in 2010.

5.3.3 Chlorofluorocarbons

A particularly stark and potent warning of the dangers of polluting the atmosphere with ‘foreign’ substances was provided by the discovery, in the 1970s, of a ‘hole’ in the stratospheric ozone layer over Antarctica. Ozone (O_3) is a form of oxygen, which shares three atoms in its molecule, whereas the ubiquitous oxygen (O_2) emitted by plants and inhaled by animals, shares two. It was discovered in the 1830s, but the identification of the role played by ozone in the upper atmosphere did not occur until the 1920s and is attributed to Gordon Dobson (1889–1976) and F.A. Lindeman (1886–1957). In the early days of research into ozone, the gas was treated as a scientific oddity, but by 1948 its presence in the atmosphere needed to be better understood and an International Ozone Commission was set up to do this [7]. A substantially funded and sustained effort to measure atmospheric ozone began in 1957—the International Geophysical Year. Measurements by instruments attached to helium balloons, or carried in high flying aircraft, or in the case of recent monitoring, built into satellites, have been executed. Generally, these have relied on spectroscopic techniques employing equipment designed to detect solar photons as they are modified by absorption, emission and scattering by gases in the atmosphere. Instruments are mostly tuned to be maximally sensitive to infrared signals since the gases of interest exhibit their greatest influence in this frequency range.

By the 1970s, the ozone concentration in the stratosphere, over the poles, in particular, and over other areas of the earth, had been well tabulated, and concentration levels were generally quite stable year on year. But from 1975 onwards scientists began to be rather concerned by apparent thinning of the ozone over Antarctica, and the emergence of a distinct ‘hole’ by 1995. By 2000 the ‘hole’ had become a crater extending over an area of 28 million km^2—roughly the area of Mexico! That the phenomenon was not due to instrument error but was associated with ozone eating chlorofluorocarbons (CFCs) was eventually established in 1974 by Paul Crutzen, F.S. Rowland and M. Molina, recipients of a Noble prize in chemistry for their efforts. Chlorofluorocarbons, invented by industrial chemists in 1928, are organic compounds that contain carbon, chlorine, and fluorine. They are produced as a volatile derivative of methane and ethane. A profuse subclass is the hydrochlorofluorocarbons (HCFCs), which obviously also contain hydrogen.

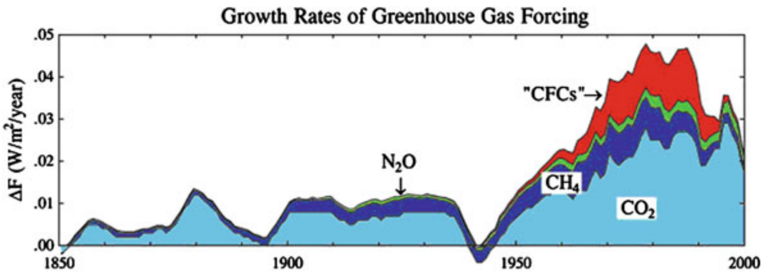

Fig. 5.2 Incremental climatic forcing due to a range of greenhouse gases

These products are quite often referred to by their trade name Freon, DuPont being by far the most prolific manufacturer. The most common representative is dichlorodifluoromethane (R-12 or Freon-12). Acceptance by industry and users of these products was mainly attributable to the fact that they were non-reactive and stable, and therefore apparently very safe. As is quite well known now, CFCs were produced in large amounts for use as refrigerants, propellants (in aerosol applications), and solvents.

In the lower atmosphere, CFCs act as powerful greenhouse gases as they percolate up through the atmosphere to the stratosphere. A CFC molecule released at ground level takes, on average, about five years to reach the edge of the biosphere. It is clear from Fig. 5.2 when CFC production was at its highest, between 1970 and 1990, that this gas contributed to the rate of increase of greenhouse gas 'forcing' by an amount which was almost 50% of the level attributed to CO_2. Climatologists talk about a process of 'radiative forcing' (see Chap. 12) when quantifying the influence of atmospheric carbon on natural global warming [7]. The earth is continually warmed by radiation from the sun. In fact, if you were to try to gather this solar heat over a square metre of the earth's surface in daytime (obviously you would collect much more at the equator than at the poles) you would garner on average about enough heat to boil a three litre kettle of water. The sun produces, as one might anticipate, high energy radiation, which impinges on the earth's atmosphere in the form of photons at light and higher frequencies. Some of these are scattered back out to space while the rest penetrate to the surface of the planet, with little absorption by the CO_2, and other greenhouse gases. On the other hand, as we have seen, low energy radiation from the 'hot' earth is at a much lower frequency and can be absorbed by greenhouse gases in the atmosphere. In 2008, man-made CO_2 was producing 'forcing' (greenhouse warming) equivalent to 0.7% of the natural level; about enough solar power over a square metre of the earth's surface to boil a table-spoon full of water. What this means is that a small fraction of radiation from the planet, which would normally propagate back out into space, is not permitted to do so by the enhanced CO_2 'blanket', and adds 0.7% to atmospheric and surface warming, as dictated by the laws of thermodynamics.

CFCs are long-lived in the lower atmosphere because the very stability, which was deemed to be an advantage for human use, prevents it breaking down and losing its potency as a greenhouse gas. However, when it reaches the stratosphere by natural convection processes, it becomes exposed to intense ultraviolet radiations which cause the CFC molecules to fracture and release chlorine atoms. Chlorine is very reactive and at temperatures below −43°C is particularly destructive to ozone. These conditions occur in the stratosphere over Antarctica and hence the alarming 'ozone hole' appeared here first.

Sky blue ozone is this colour to the human eye because ozone molecules scatter electromagnetic waves at the blue end of the electromagnetic spectrum, all other light frequencies passing through the atmosphere undisturbed. While ozone does no more than scatter electromagnetic waves in the 'blue' region of the frequency spectrum, at slightly higher frequencies, namely in the ultra-violet range, ozone actually blocks the passage of electromagnetic waves—a 'service' which is critical to life on the surface of the earth. In fact a 'healthy' ozone layer protects us from 95% of the UV which reaches the earth. Consequently, the 'hole' which began to appear over Antarctica in the 1970s was beginning to cause alarm by the 1980s. Nevertheless, it took more than a decade from the appearance of Crutzen's 1974 paper linking ozone depletion to CFCs, before urgent calls for CFCs to be banned, began to be taken seriously. Not surprisingly, the reason for the delay was denial of the science by vested interests supported by the largely right wing media in the industrialised West. DuPont, the company responsible for the bulk of CFC manufacture, in association with other producers, launched a virulent publicity campaign debunking the science and discrediting the scientists in order to distance their products from the ozone problem. The pattern is not unlike what is happening today with climate science and global warming.

Fortunately however, on the basis of computer based reconstructions of the growing ozone hole appearing regularly on television and of nascent indications of rising rates of skin cancer, public pressure began to overpower, the industrially inspired, disinterest and disengagement evinced by politicians and governments, to such an extent that twenty nations met in Vienna in 1985 and signed the Vienna Convention for the Protection of the Ozone Layer [8]. Initially it was thought to be no more than 'a toothless expression of hopes' [9], rather like the agreements emanating from Kyoto (2004) and Copenhagen (2009) on greenhouse gases. But it was followed up in 1987 by the 'Montreal Protocol on Substances that Deplete the Ozone Layer', which obliged governments around the world to phase out the use of CFCs. It came into force on the 1st January 1989, and interestingly it employs direct regulation to enforce the phase out of harmful gases, with specific timetables set for each chemical. Demonstrably, this protocol has been very effective. Looking back from 2010, the instrumental measurements indicate clearly that ozone depletion peaked in about 1990. This is confirmed by Fig. 5.2 which indicates that CFC concentration in the atmosphere fell markedly in 1990 as a result of the emissions restrictions enforced by the protocol, although the restoration of the ozone layer will not be complete until the end of the twenty first

century. This initial success was highlighted in a 2007 report of the Netherlands Environmental Assessment Agency in the following way [8]:

> The 1987 Montreal Protocol—restricting the use of ozone-depleting substances—has helped to both reduce global warming and protect the ozone layer. Without this protocol the amount of heat trapped due to ozone-depleting substances would be double that of today. The benefits to the climate, achieved by the Montreal Protocol alone, at present greatly exceed the initial target of the Kyoto Protocol.

Sadly, this genuine record of achievement is not matched by the Kyoto Protocol [8], which was designed to procure reductions in greenhouse gas emissions of about 2 Gigatons/year of carbon dioxide and equivalent gases (Gt CO_2 eq/year) by 2012. This compares very unfavourably with the 18–25 Gt CO_2 eq/year, which will potentially be achieved by the Montreal Protocol. On current trends, even the risible Kyoto target will not be reached, and the shambolic Copenhagen treaty will have no significant effect on emission targets. As Tickell [8] expresses it:

> Th[e] relatively easy and rapid success of the Montreal Protocol in tackling greenhouse gas emissions stands in stark contrast to the slow, meagre and expensive gains achieved under the Kyoto Protocol.

It seems that until the mass of the population, in countries around the globe, becomes seriously concerned and noticeably agitated about global warming, as they did about the ozone hole, so making the issue politically important, governments will not give the problem the attention and consideration it deserves. Had scientists been predicting that human activities were inducing the onset of global freezing leading to a new ice age the response, one suspects, might have been very different. 'Global warming', does not seem threatening. It instils the illusion of a comfortable, warm future, which is a rather attractive notion for humans—being an essentially tropical species which in geological terms has quite recently emerged from Africa.

5.3.4 Heat Waves

In the summer of 2007 Europe, and particularly Central-Eastern regions, suffered a prolonged and record breaking heat wave. In Hungary the summer was exceptional with the heat wave experienced there outstripping all previously events, becoming the longest and hottest on record. As it happens, European funding of research into the relationship between temperature and mortality, which was being pursued at the University of Birmingham in conjunction with institutions in Hungary, has led to the accumulation of copious statistical data for the period [10]. Temperature data for five summers, including 2007, are presented in Table 5.1. The recorded data is essentially for Budapest where temperature measurements were performed at a fixed site in the outskirts of the city.

The first two rows in Table 5.1 show measured mean and maximum temperatures for Budapest taken over the period 1st June to 31st August for each of the

Table 5.1 Summer temperature and related data in Budapest 2003–2007

	2003	2004	2005	2006	2007
Summer mean temperature (°C)	23.6	20.8	20.5	21.5	23.3
Summer maximum temperature (°C)	39	34	35	37	41
Number of days with mean temperature less than 25°C	44	82	78	51	46
Number of days with mean temperature greater than 25°C	35	8	9	30	29
Number of days with mean temperature greater than 27°C	13	2	5	11	12
Number of days with mean temperature greater than 30°C	0	0	0	0	5
Number of heat waves	2	1	1	5	3
Number of days of heat waves	11	4	5	30	19

Table 5.2 Excess mortality in central Hungary during 2007 heat waves

	June 19–23 second level alert 5 days	July 15–24 third level alert 10 days	August 23–26 Heat warning 4 days
Number of deaths	400	1123	341
Number of excess deaths	−23	278	3
Mean daily number of excess deaths	−4.5	27.8	0.75
Daily excess mortality rate (%)	−5.3	32.9	0.9

years tabulated. It is clear that 2007 was only slightly worse than 2003 on this criterion. However when numbers of days, when the temperature exceeded the 25°C, 27°C and 30°C levels, are examined, which tends to highlight the depth and severity of the heat waves, the 2007 event was clearly more severe than 2003 with five days when the temperature exceeded 30°C. There were three heat waves (daily mean temperature exceeding 25°C on at least three consecutive days) in the summer of 2007. The first, which was accorded a 2nd level alert, occupied five days (19–23 June) with a daily maximum of 35°C and a 5 day mean of 25.9°C. The second was classed as a 3rd level alarm and lasted ten days from 15 to 24 July during which daily maximum temperatures exceeded 40°C with the highest reading being 41°C on 21 July—a record for Budapest. During the 4-day long heat wave in August, which attracted a 'heat warning', the daily maximum temperature was 35°C while the mean over the four days was 27°C. These statistics undeniably represent conditions, which because of their longevity are very oppressive for humans to tolerate, and they took there toll.

Table 5.2 records, on the first line, the total number of deaths in central Hungary during the period of the three heat waves in 2007, which are defined and delineated above. Taking the number of deaths, for a typical summer for which the temperature never rises above 25°C, as the norm (for example during 19–23 June, 423 deaths would be expected), line two of the table records excess deaths relative to the norm. Line three gives the daily figure, which is presented as a percentage in line 4. Although local extreme events are notoriously difficult to ascribe to climate

change, for many Hungarians who lived through this period it must have crossed their minds that global warming had touched them, and they could hardly help to be worried that this event was not indicative of a new and unpleasant climate pattern.

5.4 Nature in Retreat

5.4.1 Emergence of Agri-business

The bonanza for humans of easy access to plentiful supplies of cheap energy created by 'ancient sunshine' has resulted in unimagined prosperity for many humans, although still a small percentage of the species as a whole, which numbers almost seven billion in 2010. It has occurred over the past century and a half—but this

> interlude may prove to have been a lucky aberration, thanks in large part to the massive boost in food and energy that our civilisation derived from fossil fuels. This same fossil energy boost, of course, while allowing our species to proliferate massively in numbers, and construct wonderful complex societies in little more than a historical instant—could in the longer term prove our undoing [11][1]

Fossil fuels, more than any other exploitable planetary bounty, have procured extraordinary advancement for *Homo sapiens*. While all other species have to live within the constraints of, and are regulated in numbers by, their ecosystems, through variable food availability and predation, *Homo sapiens* has largely escaped from this ecological confinement. As Lovelock [2] observes:

> We have severed nearly all the natural physical constraints on the growth of our species: we can live anywhere from the Arctic to the Tropics and, while they last, our water supplies are piped to us: our only significant predator now is the occasional micro-organism that briefly mounts a pandemic. If we are to continue as a civilization that successfully avoids natural catastrophes, we have to make our own constraints on growth, and make them strong, and make then now.

Our food supply is no longer constrained by what we can grow naturally or what we can acquire by foraging and hunting. We have discovered how to convert fossil fuels to food and to produce and deliver it to anywhere in the world by means of effective and successful, but hugely fuel dependent and planet ravishing,

[1] If you were able to read only one book about the implications of global warming this would have to be it. It is comprehensively researched, beautifully constructed and well written, and it spells out clearly and graphically the consequences of warming for ecosystems, biodiversity, climate and local weather patterns around the world, at each one degree rise in temperature above that which prevailed before the industrial revolution. Needless to say, the implications for human civilisation are shown to be perilously hard and difficult, if the average global temperature should creep to 2°C or more, beyond the pre-industrial benchmark.

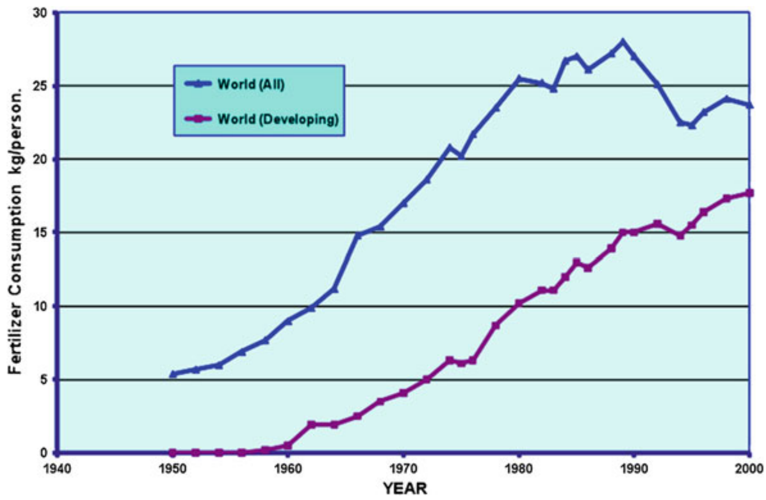

Fig. 5.3 Growth in fertilizer use in the world as a whole, and in the developing world since 1950 (Worldwatch Institute 1999)

agri-businesses. But emerging evidence indicates that this success for humanity is reaching its limits.

The trend in agricultural expansion is shown in Fig. 5.3 where fertilizer consumption per head of population is plotted over the period 1950–2000, for the world as a whole and for the developing world. Clearly up until 1990 the fertilizer consumption in kg/person, and hence farming output per person, has advanced ahead of population growth. Thereafter, rather worryingly, it slumps. This is because, while population continues to expand rapidly, land for agriculture in the industrialised world peaks, as the towns and cities housing burgeoning human populations, encroach into the countryside. Crop yield and fertilizer requirements plateau resulting in the observed levelling off in the per person statistics—although not yet, interestingly, in the developing world, where land for new agricultural enterprises still exists. In energy terms these modern agricultural practices are by no means efficient. According to one estimate [11, 12], agri-business in the United States uses at least ten units of fossil fuel energy to produce one unit of food energy! Further, as we have seen, most of this fossil fuel energy, by being combusted in inefficient engines, ends up as atmospheric pollution. Agribusinesses also cause indirect pollution by the clearing of climax ecosystems to provide land for mono-culture crop systems, which are much less effective environmental controllers. Climax ecosystems such as rain forests provide essential oxygen, cooling functions, pollution absorbing functions, reliable rain patterns and clean water etc. These are the ‘externalities’ which are invariably zero-costed by economists in formulating business plans and in developing national economies.

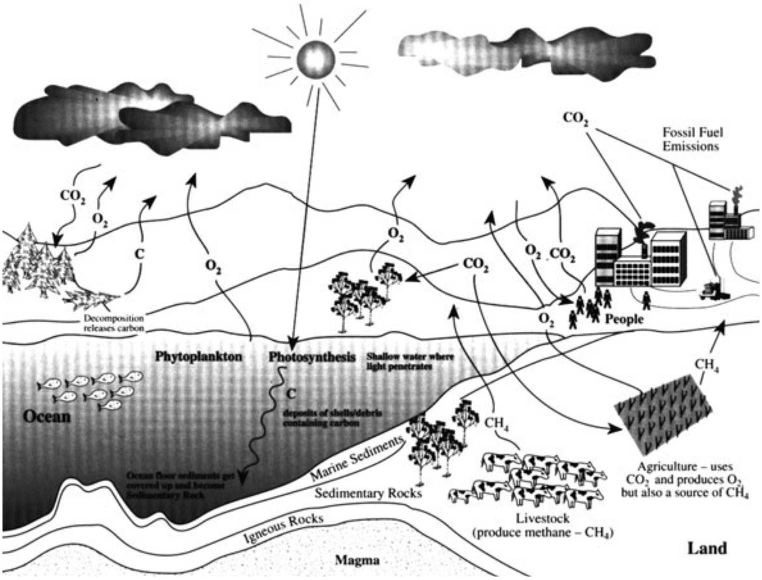

Fig. 5.4 The fundamental elements of the carbon cycle

5.4.2 Artificial Food Chain

The intrusion of the industrialised world into the biosphere is represented in a familiar schematic depicting the well established carbon cycle (Fig. 5.4) and the food chain, in trophic form in Fig. 5.5, where the idealised trophic diagram previously shown in Fig. 4.10, has been modified by the presence of a second energy flow sphere representing human activity. While the natural trophic diagram represents energy, originating in the sun, flowing to the carnivores, including man, through the agency of food, the artificial diagram also incorporates energy from ancient sunshine flowing through the agency of fossil fuels—represented by a sun motif with an embedded dinosaur. This artificial sphere is shown abutted onto the sphere representing the natural world. The relative sizes of these spheres and the degree to which they are in contact is open to conjecture and debate. The criterion for judging these relativities has to be related in some way to the impact of human activities on the global environment. It is now largely unquestioned that modern humans are modifying the planetary atmosphere sufficiently strongly to be upsetting the ecological balance. As Fig. 5.4 suggests, the natural flux of carbon in the atmosphere, in the soil, in sea and ocean surface layers and in flora and fauna is essentially in balance, and has been for millenia. Needless to say, the additional contribution to the flux, by 6.7 billion people combined with their domestic/farm animals and their fossil fuel hungry economies, is very significant indeed. During the

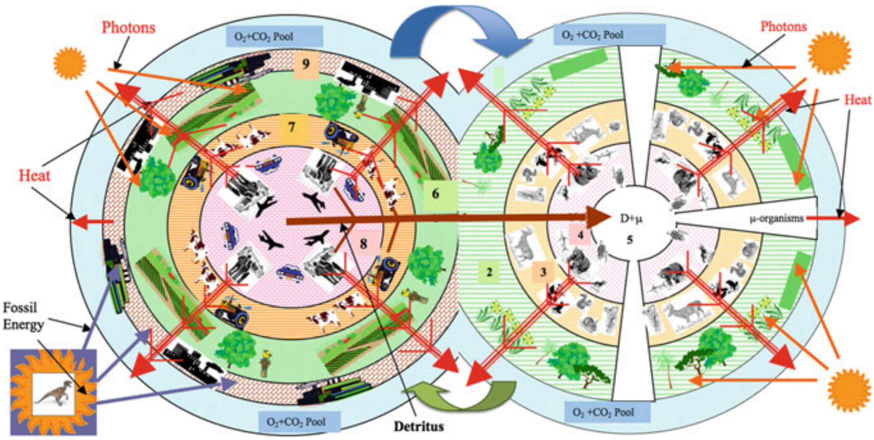

Fig. 5.5 Trophic diagram representing the natural ecosystem (*upper half*) in harness with modern man's artificial ecosystem (*lower half*). The *upper half* of the diagram is largely a replica of Fig. 4.4.1, while the lower half represents energy flow, including fossil fuel energy, represented by the Sun with an embedded dinosaur

1990s the statistical data suggests that human activities generated 13.5 Gt/year of greenhouse gases, with 6.5 Gt/year coming from fossil fuel combustion. Consequently, in Fig. 5.5, the trophic-spheres have been chosen to be depicted as essentially equal in radius. It is presumed that in order to have the measurable degree of influence on the biosphere, which the artificial ecosystem created by humans displays, it cannot be too different in magnitude (whatever that means) to the Earth's ancient and natural ecosystem. The volume of the artificial sphere could perhaps have been chosen to exceed that of the natural sphere, given pronouncements by Lovelock [2] and others that we need two additional planets to accommodate current economic activities. The degree of contact between the two systems is also debatable. Dividing a single trophic sphere into natural and artificial hemispheres would suggest that a level of interaction and coupling between the two worlds exists, which is simply not plausible. On the other hand, they certainly cannot be uncoupled (two independent spheres) as the economists obviously would prefer. The choice shown is essentially just an illustrative compromise, but hopefully it is also helpful and thought provoking.

The portion of the trophic diagram (Fig. 5.5) which is representative of man's artificial ecosystem, exhibits an additional shell (9) located just inside the outer $O_2 + CO_2$ shell. This shell represents industrial development. Here 'ancient sunshine' is consumed and digested, and in biospheric terms, this shell spews out unprecedented levels of CO_2 and detritus—represented by the heavy arrow (marked-detritus) directed to the right from the centre of the artificial sphere. This thermodynamically produced waste inevitably finds its way into the natural world (right portion of Fig. 5.5) as is indicated on the diagram.

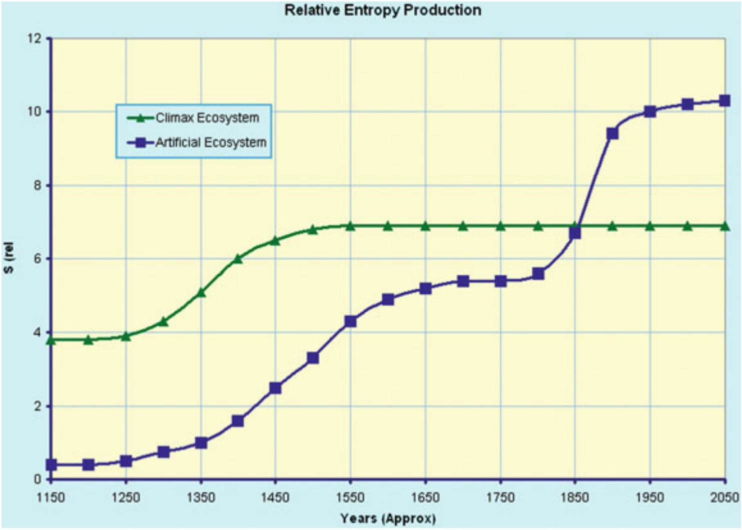

Fig. 5.6 Qualitative comparison of entropy production in climax and artificial ecosystems (adapted from Ref. [13])

In the artificial ecosystem, the trophic region which was occupied by the autotrophs in the natural world, has been taken over by crop farming (shell 6), while the heterotrophic shell (7) occupied by the herbivores, in Fig. 4.10, now represents animal husbandry. Within these shells, an inner spherical region (8) contains the carnivores, now represented wholly by mankind, which doesn't just eat agricultural products, of course, but burns copious volumes of fossil fuel, creating large amounts of greenhouse gases and detritus for the natural world to absorb. This activity is represented by the aircraft and car symbols. Waste transmission between the artificial and natural systems is portrayed by the large rightwards directed heavy arrow as indicated earlier, while the large green (light shading) and blue (dark shading) coupling arrows on the right and left of the schematic depict the 'trading' of O_2, clean H_2O, and CO_2 ('externalities' in economic terms) between the two systems. The four radially directed 'triple-line' arrows in each half of the diagram denotes heat loss in accordance with the first law. Quite clearly, man's artificial ecosystem is inextricably linked to the natural biosphere, which being 'finite' places an unavoidable and impenetrable barrier to continuing economic development, particularly when it is considered in tandem with the dilemma presented by unsustainable population levels, a problem which is growing inexorably.

It is perhaps relevant to ask, in relation to the artificial ecosystem, which today revolves around fossil fuel boosted agri-business, why it is unsustainable. Part of the answer is to be found in Fig. 5.6, where the entropy production of an artificial ecosystem is compared qualitatively with that of a natural, highly bio-diverse, climax ecosystem [13]. For the reference climax system in Fig. 5.6, it is presumed

that the diversity of living organisms within it maximise the rate of entropy production relative to what would have occurred in the same area of the planet in the absence of life. Given our earlier discussion in Chap. 4, it can therefore be assumed that the maximum rate of entropy production by the climax ecosystem must be the optimum sustainable rate attainable for the solar flux on the area of the planet in question. Consequently, when the rate developed by an artificial ecosystem in the same corner of the planet becomes greater than the climax system, it has to be presumed that it is not sustainable in the long run.

Prior to the industrial revolution and agri-business, agriculture with its limited crop range created a diminished ecosystem relative to the natural ecosystem which it replaced. In fact, the mono-culture crop stands on farmed land are not too different in character to an early successional stage in a climax ecosystem. Not surprisingly, therefore the entropy production of 'artificial' agriculture before 1,800 is never as high as is achieved by the climax system (Fig. 5.6). In addition, agriculture promotes soil erosion which is increasing and accelerating. This implies that farming practices may lead to a net loss of soil organic matter, because the input of new organic matter by natural recycling is reduced and because soil temperature is increased—it is cool within pristine forests. So, the opening of the entropy gap in favour of agriculture after 1850 is an obvious indicator of practices which deviate substantially from the sustainable level.

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